Ph.D. Synopsis

Spatio-Temporal Evolution of the Mantle and the Continental Crust: A Geochemical Perspective

Existing Geochemical Models:

Global mafic magmatism is essentially derived from asthenosphere, lithosphere and deep mantle sources generally exhibited in the form of mantle plumes. Although, we have enough geochemical tools to distinguish melts derived from these mantle sources, our understanding on how these mantle sources themselves are generated is far from satisfactory. It has been argued that removal of melts, which eventually formed the continental crust, from the primitive mantle in the early stages of Earth's evolution has produced the mantle with depleted trace element and isotopic signatures – the present-day Asthenosphere (Hoffman, 2008). The oceanic crust continuously derives from this depleted mantle reservoir. However, presence of small degree melts derived from the deep mantle sources, delaminated continental lithosphere and subducted oceanic crustal material make the asthenosphere geochemically heterogeneous. Our understanding of the generation of plume and continental lithosphere sources and mapping of their geochemical heterogeneities is even sketchier. The geochemical heterogeneities in the plume sources may originate from 1) oceanic crust injections (Hoffman, 2003), 2) delamination of continental lithosphere (McKenzie and O'Nions, 1995) or 3) injection of upper crustal sediments (Hawkesworth and Schersten, 2007 and references therein). With many episodes of melt depletions and material additions from different geochemically distinct mantle and crustal reservoirs makes the continental lithosphere the most heterogeneous geochemical reservoir in the planet Earth.

Partial melting is the main process of mantle differentiation and is the main tool for us to map the different mantle reservoirs. Characterization of the behavior of elements during mantle melting in different tectonic environments is fundamental to our understanding of mantle heterogeneity and chemical budget of continental and oceanic crusts. The elements which preferentially partition into the liquid (incompatible elements with $D \ll 1$) would be very

sensitive to different degrees of melting. However, it is found that some of the trace element ratios are independent of mantle melting and fractional crystallization processes, as a result are widely used for identification different mantle reservoirs. Thompson et al. (1984) and Hofmann (1988) modeled the elemental incompatibility to understand the melting mechanisms and mantle source characteristics. Gast (1960), Arth and Hanson (1975) and Sun and Hanson (1975) illustrated the importance of minor phases on the melt incompatible element compositions during low degree partial melting. Since sources are controlled by tectonic environments, the incompatible elements in the mantle-derived primary basaltic melt consequently through light on the geodynamic settings (Holm, 1989). Based on our studies of dynamic partial melts we will make an attempt to examine the relative incompatibility of the trace elements during partial melting of mantle sources in different tectonic environments.

Elucidation the origin and growth of continental crust is a fundamental problem in Earth sciences. Two divergent ways in which the continental crust generates include subduction (horizontal) and plume/extension (vertical) accretions. In the subduction environments, the continental crust is grown by accumulation of island arcs and development of continental magmatic- and back-arcs whereas in the extensional settings, the continental crust is essentially grown by addition of asthenosphere-/plume-derived mafic melts and their differentiates. As the mantle reservoirs in these two tectonic settings are presumably generated and/or modified by contrasting processes, the erupted melts offer clues on the nature of these distinct mantle sources. Another important question being how much of the present day crust represents juvenile addition and how much is recycled from the older crust. A corollary to this is the rate of continental crust generation. Again two distinctly different models include 1) continuous generation of the continental crust from the Archaean to present or 2) generation of a large proportion of the crust in the Archaean itself and most of the present day crust represents recycling of this older crust at different time domains in the later history. Trace element geochemistry is a robust tool to quantitatively model the mantle sources, melting mechanisms and relative roles of mantle melting and crust recycling in the chemical configuration the present-day continental crust.

A fundamental question concerning continental crustal growth models is whether Phanerozoic models of melt generation in the lithosphere and asthenosphere/plume are

applicable to the Archaean/Proterozoic or there is any temporal variation in the melt generation processes in the mantle. If we presume that the melting generation processes did not change over time, then is it possible to map the geochemical characteristics of the mantle reservoirs by inverting primary melt geochemistry? Addressing this problem is paramount to geochemically model the continental crust generation. Parameterization of geochemical models of continental crustal growth involves evaluating mantle source reservoirs and their spatio-temporal variation. For example, attending post-accretion growth of the arc/back-arc, subduction-related lithospheric sources are replaced by plume/asthenosphere upwelling and related mafic magmatism, finally culminating with the emplacement of potassic mafic melts. Thus the compositional timeline of erupted magmas in a given terrain reflect changing deep-seated mantle reservoirs. These geochemical changes in mantle source compositions and generation of new mantle reservoirs is the cornerstone of plate- and plume-tectonics.

Analyses of the existing geochronologic data on the zircons from the continental crust show peaks at different time domains which are correlated with supercontinental cycles. Whether the amalgamation of the continental masses results in new continental crust generation or simply recycles the existing curst is another tantalizing question to ponder about in our attempts to model the continental crust generation and evolution. In addition to zircon data, analysis of crustal xenoliths is another tool that has been utilized to evaluate the continental crustal processes.

Hypothesis of the proposed work:

The solid sphere of the planet has been differentiated into core, primitive mantle and crust. Post this primordial differentiation there has been continuous communication between primitive mantle and crust through partial melting, mafic magma generation, delamination and subduction. However, we are not aware of any material supply from the outer core after the early differentiation. The in- and out-flow of material has generated distinct geochemical reservoirs especially within the upper mantle constituting the asthenosphere and lithosphere. Additionally, the deeply subducted oceanic lithosphere and/or delaminated continental lithosphere may get

heated-up at thermal boundaries (mostly at core-mantle boundary) and rise as mantle plumes, adding a third dimension to the mantle geochemical spectrum (Fig. 1).

The earliest continental crust may have generated by low degree melting of the primitive mantle and the oceanic crust by melting of depleted asthenosphere. However, we are not sure on how much of the present day crust represents juvenile addition at subduction zones and how much is recycled from the older crust. A corollary to this is the rate of continental crust generation. Further, the continental crust has been experiencing intra-crustal geochemical changes through time as controlled by sedimentation, anatexis and lower crustal foundering. It is established that the upper continental crust (UCC) composition has been changing with time. The Archaean UCC was more mafic than the Phanerozoic UCC. Whether this variation in the upper crust reflects secular changes in the mantle potential temperature need to be explored.

With this hypothesis, we wish to geochemically map the different mantle reservoirs on the basis of erupted mafic magmas, interactions between different reservoirs, relative contributions of mantle reservoirs to mafic magmatism in different tectonic settings, estimating the composition of the continental crustal, especially with respect to the Indian sub-continent.

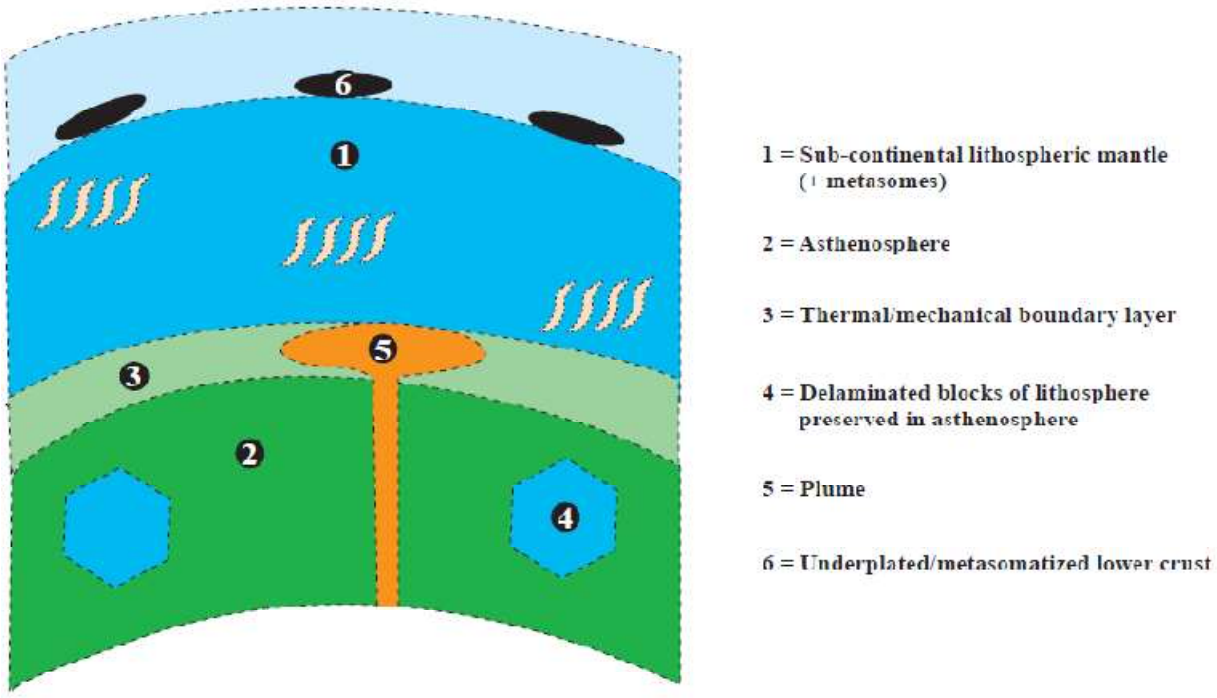

Fig. 1. Different Mantle and Crustal Reservoirs

Objectives:

In the proposed work under the Ph.D. program of the SRTM University, we would make an effort to identify the end-members of the different mantle reservoirs and quantitatively model the mixing trajectories between these compositions to explain the geochemical variations observed in the erupted basalts. We will also endevour to model the relative contributions of different mantle reservoirs to the mafic magmatism in distinct tectonic environments. For this purpose we will utilize the global geochemical data banks and generate our own geochemical data on the mafic magmatism. Additionally, we will make an attempt to understand the continental crust generation using 1) trace element geochemistry, 2) zircon data and 3) xenolith data from selected geologic terrains from India and elsewhere. Results from the proposed study will be of interest to global geological community involved in unraveling the history Earth's upper solid layer.

Methodology:

Large amount of bulk-rock geochemical data including major, trace and rare earth element abundances and isotopic compositions on the igneous [from ultramafic (komatiite) to felsic (rhyolite) geochemical spectrum] and sedimentary (from sand- to clay-size sediments) will be filtered from the global data banks. Geochemical data on the igneous and sedimentary rocks from all the spatial (tectonic environments) and temporal (Archaean to present) will be considered to test the spatio-temporal variation of mantle and crustal magmatism. The geochemical data will be analyzed using the standard graphical representation of the data. Relevant petrogenetic parameters will be calculated wherever necessary. Mathematical modeling of the geochemical data will be done to propose plausible models. Required new geochemical data will be generated on the geologic units from the Indian subcontinent.

Work plan:

First Year:

Literature Survey

A review of published literature on Indian and global magmatism will be carried out, especially denoting the existing geochemical models on mantle and crustal reservoirs.

Data compilation

Large amount of bulk-rock geochemical data including major, trace and rare earth element abundances and isotopic compositions from ultramafic (komatiite) to felsic (rhyolite) geochemical spectrum will be filtered from the global data banks. Geochemical data from all the spatial (tectonic environments) and temporal (Archaean to present) will be considered to test the spatio-temporal control on mantle and crustal magmatism.

Second Year:

Data analysis and generation of new geochemical data

A large number binary and ternary variation plots will be prepared through graphical representation of the data. Relevant petrogenetic parameters will be calculated wherever necessary. Mathematical modeling of the geochemical data will be done to propose plausible models. To test the proposed geochemical models on the Indian crustal components, new geochemical data will be generated on spatio-temporally distinct geologic units from the Indian subcontinent. Geochemical analyses will be carried out in the Geochemical Laboratories of National Geophysical Research Institute (NGRI), Hyderabad and in the School of Earth Sciences, SRTM University.

Third Year:

1. **Interpretation of Data: G**eochemical data will be synthesized and interpreted.
2. **Writing and Submission of Thesis:** The thesis will be written after the interpretation of data and achievement of objectives and will be submitted at the end of third year.
3. **Presentation in Seminars** at national and international level.
4. **Publication of research papers** in National and International Journals.

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